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Commentary

A sense of sustainability? – How sensory consumer science can contribute to sustainable development of the food sector

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ABSTRACT

Background: Humanity's current use of resources is not in line with the goal of sustainable development. Climate change impact scenarios appear worryingly pessimistic. The agricultural and food production accounts for a particularly high share of the impact, and this also holds for consumption of food. Transforming food consumption plays a crucial role in tackling the challenges, and sensory consumer science can contribute to this.
Scope and approach: This commentary examines what is required of the agricultural and food sector in order to sustainably transform, and outlines the current research streams in sensory consumer science from a sustainability perspective. Based on a comparison of the requirements and research, we suggest a categorization of the contributions that sensory consumer science can make to sustainable development.
Key findings and conclusions: Six necessary transformations to which sensory consumer science can make a contribution are derived and outlined: 1) promotion of a dietary shift towards more sustainable foods and diets, 2) increase of food diversity, 3) food waste reduction, 4) enhancement of the circularity of the food system, 5) heightening and prioritising food-related well-being, and 6) coping with the effects of climate change. So far, sensory consumer science studies have focused on foods regarded as sustainable (e.g. organic, sustainably claimed, insects and meat alternatives) as well as issues that contribute to sustainability (e.g. shelf-life, fruit and vegetable consumption, unfamiliar food). The conclusion for further future research is that designing sensory consumer science research to explicitly target the six required transformations can increase the discipline's contribution to sustainable development.

1. Introduction

1.1. The need for sustainable development in the food sector

We are frequently faced with media reports that refer to the looming threat that climate change poses to our society (Schmidt, Ivanova, & Schäfer, 2013). The ice caps are melting, extreme weather like heat waves and rain storms are becoming more frequent (IPCC, 2014), and desertification induces migration of people who cannot make a living on their land anymore. The need to change the current course of human activity is underlined by policy makers and scientists (Alfredsson et al., 2018), and citizens are required to change their lifestyle to contribute to 'sustainability' and 'sustainable development'. Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987). A growing share of environmentally conscious consumers actively attempt to change their behaviour, but their contribution is yet trifling in face of the changes needed across the globe (Alfredsson et al., 2018).

Not all members of the current generation can meet their needs. Despite decades of policy efforts, there is still a considerable number of undernourished people (FAO, 2017; FAO, IFAD, UNICEF, WFP and WHO, 2017). In addition, whether future generations will be able to meet their food needs seems uncertain. The projections of population increase on the one hand and climate change affecting the capacity to produce food on the other hand constitute a huge challenge for future food security (FAO, 2017). Agriculture has been pointed out as a sector with a strikingly large share of greenhouse gas emissions (Garnett, 2011). Agricultural and food production need the planetary ecosystems for which secure boundaries of use have been exceeded (Steffen et al., 2015). Food consumption accounts for about 20–30 percent, in some cases up to 50 percent of the various negative environmental impacts

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considered (EC, 2006). A great share of the poor live in rural areas and depend on the agricultural and food sector for their livelihood, (FAO, 2017), and this contributes to the sector's key role for sustainable development in both an environmental and social perspective.

The impact of human activity on earth in terms of a 'footprint' is often described by the IPAT formula. This equation explains that population growth (P) and affluence levels (A) increase the impact (I), while technological innovations (T) can both increase or alleviate it (e.g. by either heightening demand, or improving resource efficiency) (thus Impact = Population x Affluence x Technology; Ehrlich & Holdren, 1971). Consumption exerts an influence through population size as well as the extent of 'need' per capita. It is often pointed out that humanity in fact possesses the technology and new approaches needed (Pacala & Socolow, 2004) to keep impact within safe boundaries. However, policy action is needed to enforce the technology and processes, sector stakeholders must collaborate, and consumers must accept and demand more sustainable products as well as alter their individual consumption patterns (Thøgersen, 2014). In particular individual consumer lifestyle choices and their dietary eating patterns, are the key to sustainable development.

1.2. Role of sensory consumer science

An already wide range of technologies and innovative approaches exist for sustainably managing and intensifying the agricultural supply chain. These can be applied to increase food production while also conserving or re-establishing the natural resource base (Foley et al., 2011). Moreover, it is known which major consumption pattern changes consumers should engage in (Reisch, Eberle, & Lorek, 2013). Consumer trends can be observed which are positive in this regard, such as organic food (Hemmerling et al., 2013), vegetarian or flexitarian diets (De Boer, Schösler, & Aiking, 2014), and food waste avoidance (Stuart, 2009). Among the many barriers to dietary change are sensory and hedonic perceptions of and expectations towards food (Hartmann & Siegrist, 2017; Piqueras-Fiszman & Spence, 2015). Food serves various short and long-term goals that may be contradictory, such as hedonic experience versus health outcome or environmental impact (Sautron et al., 2015), and consumers do not want to trade-off the first for the latter.

Sensory food science, defined as the multidisciplinary study of "human sensory perceptions of and affective responses to foods, beverages and their components" (Tuorila & Monteleone, 2009, p. 54), plays a crucial role in studying how food preferences and expectations are shaped. It can lead to a better understanding of how consumers perceive more sustainable foods and the factors that should be modified in order to increase acceptance. Work in this research discipline can contribute to the economic sustainability of food companies and to support food security as well as environmental and social sustainably. This will allow alignment of the three pillars of sustainability: economic, social and environmental aspects (Visser, 2009).

In this commentary, we aim to outline how sensory consumer science (Tuorila, 2015) can contribute to the further sustainable development of food production and consumption. We do so by firstly, examining the predictions and requirements for a sustainable transformation of the food sector or the adaptation to climate change impact. Secondly, we outline the current research streams in sensory consumer science from a sustainability perspective. Finally, we derive a categorization of the transformations needed to meet the sustainable development challenges ahead and discuss how sensory consumer science can make a contribution.

2. Requirements for sustainable transformation

We recap the actions required to secure sustainable development, according to what researchers have outlined. Overall, it is demanded that 'action is needed on all fronts' (Röös et al., 2017b) and the whole range of the 'portfolio of investments' (Keating, Herrero, Carberry, Gardner, & Cole, 2014) should be used. This includes a range of technologies (Mc Carthy et al., 2018) and changes of a radical nature (Horton, 2017).

2.1. General sustainable transformation

Holden, Linnerud, and Banister (2014) recommend four indicator thresholds. These should ensure that humanity is positioned in what is called the 'sustainable development space'. These thresholds are of social nature on the one hand, with achieving social development equivalent to an at least medium human development index of 0.63, and intra-generational equity of sufficiently equal wealth distribution expressed by a maximum Gini coefficient of 40. On the other hand, these thresholds are of on environmental issues, with keeping resource use to an ecological footprint at max 2.3 global hectares per capita, as well as securing inter-generational equity via stabilizing climate change through a renewable energy share of at minimum 27 percent. Steffen, Richardson and Rockström (2015) highlight the need for humanity to keep within the 'safe operating space' of nine ecological subsystems of earth. They warn that it is important to refrain from crossing thresholds beyond which abrupt changes might happen (Steffen et al., 2015). These boundaries are already overstepped as regards biodiversity loss (in particular genetic diversity, but undetermined with regard to functional diversity), and the nitrogen and phosphorous cycle, while climate change and land-use change are in the zone of uncertainty. Therefore, urgent improvements are needed to alleviate the use of these ecosystems.

2.2. Agriculture and food sector transformation

These general challenges translate into the recommendation to halt further expansion of land used for agriculture, to increase yields on lands where crops underperform, while improving efficiency of the resource input (e.g. irrigation, fertilizers) (Foley et al., 2011). In addition, food loss and waste should be reduced to increase the ratio of food usage, and a shift in demand away from meat is called for in order to produce more food for human consumption with the crops currently used for livestock feeding (Foley et al., 2011). Keating et al. (2014) have organised these recommendations into 14 so-called 'food wedges' of sets of actions to sustainably satisfy food demand projected for 2050, sorted into three main groups. These three groups are called first 'reducing food demand' (e.g. reducing waste, overconsumption and meat demand and shifting biofuels to renewables not competing with food), second 'filling the production gap' (e.g. increasing production, yields, and efficiency), and third 'avoiding losses in production potential' (e.g. safeguarding against degradation, risks to production by disease and resistance, and climate change effects mitigation; Keating et al., 2014).

2.3. Consumer demand transformation

For the demand side, scenarios are rather clear about the crucial role of dietary shifts. Findings show that it would be difficult to fill the production gap by sustainable intensification only (Hyland, Henchion, McCarthy, & McCarthy, 2017). Without waste reduction, protein supply of the magnitude of all current animal protein would need to come from artificial sources in the future (Röös et al., 2017a; 2017b). Healthy diets can only be sustainable at the same time if meat consumption is reduced (Van de Kamp et al., 2017). Recommendations to consumers thus emphasize 'cutting down' on meat and dairy products, in particular beef (Garnett, 2011; Hoolohan, Berners-Lee, McKinstry-West, & Hewitt, 2013; Reisch et al., 2013). In addition, recommendations highlight the importance of reducing food waste and avoiding airfreight food (Hoolohan et al., 2013) as well as choosing organic foods (Reisch et al., 2013).

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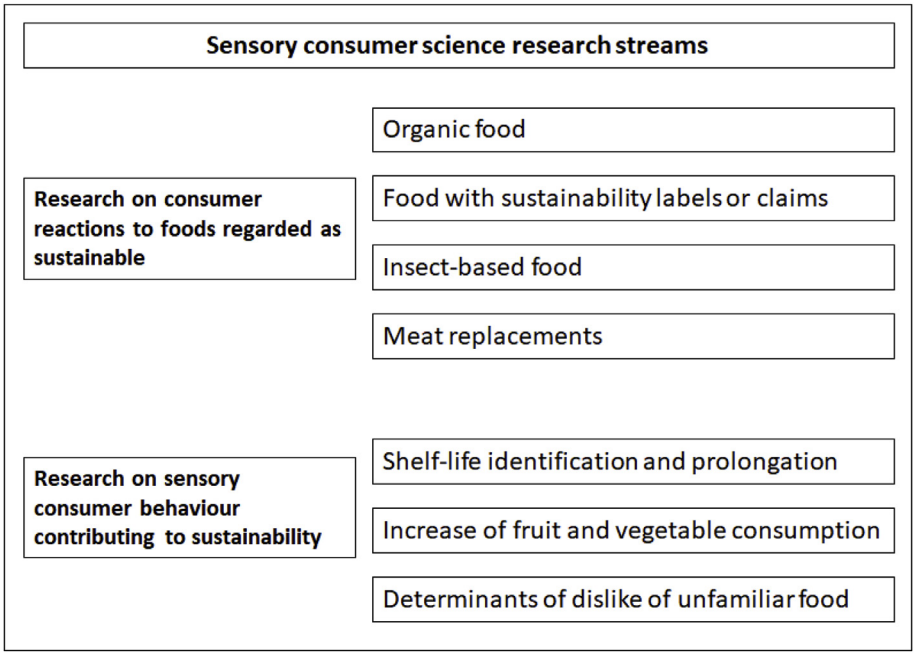
Sensory consumer science research streams
Research on consumer reactions to foods regarded as sustainable
Organic food
Food with sustainability labels or claims
Insect-based food
Meat replacements
Research on sensory consumer behaviour contributing to sustainability
Shelf-life identification and prolongation
Increase of fruit and vegetable consumption
Determinants of dislike of unfamiliar food

Fig. 1. Overview of current sensory consumer science research streams on sustainable food and relevant for sustainability.

3. Current research streams in sensory consumer science from a sustainability perspective

A number of research streams in sensory and consumer science explore consumer reactions towards foods regarded as 'sustainable'. However, there are also research streams that entail a contribution to sustainability, even though it is not the explicit research goal (see Fig. 1 for an overview).

3.1. Research on consumer reactions to foods regarded as sustainable

3.1.1. Organic food

Choosing organic food has been suggested as a sustainable consumer action (Reisch et al., 2013). A particularly large research stream has explored consumer reaction to organic food with regard to sensory expectations and perception. The studies repeatedly find that consumers generally have favourable expectations towards organic food (Ellison, Duff, Wang, & White, 2016; Lee, Shimizu, Kniffin, & Wansink, 2013; Prada, Garrido, & Rodrigues, 2017), an effect called the 'organic halo effect'. In many studies, this also extends to sensory expectations and reporting on the sensory perceptions (Apaolaza, Hartmann, Echeberra, & Barrutia, 2017; Bernard & Liu, 2017; Bratanova et al., 2015; Sörqvist et al., 2015; Prada et al., 2017; Samant & Seo, 2016; De Andrade Silva, Bioto, Efraim, & de Castilho Queiroz, 2017). The favourable expectation towards organic food holds even in studies where the actual perception in blind-testing does not match expectations (De Andrade Silva et al., 2017). The variables characterizing consumers with favourable expectations towards organic food include attitudes and beliefs in favour of organic, environmental concern (Bernard & Liu, 2017; Prada et al., 2017; Sörqvist et al., 2015), but also frequency of organic food consumption (Prada et al., 2017). One study found that consumers with greater health concerns were less prone to the halo effect (Apaolaza et al., 2017). Meanwhile, another study found that the halo effect might differ depending on whether the organic item is a 'vice' or 'virtue' food category (e.g. indulgent or healthy food; Ellison et al., 2016). Only few studies find that the halo effect might also lead to negative inferences, such as in terms of lower taste and nutritional expectations (Schuldt & Hannahan, 2013).

3.1.2. Food with sustainability labels or claims

Apart from organic food products, there are a range of other 'sustainability labels' or claims about a product's relative sustainability. Studies have been conducted exploring sensory expectation or perception towards 'local' food (Bernard & Liu, 2017; Bratanova et al., 2015), food described as from 'sustainable agriculture' or 'sustainable practices' (De Andrade Silva et al., 2017; Simoes et al., 2015), 'eco-friendly' (Sörqvist et al., 2015; Sörqvist et al., 2013), or 'fair trade' (Bratanova et al., 2015). The findings are generally similar to what has been found for organic foods. In many studies, it is found that there is a certain halo effect triggered by the sustainability characteristic, and this holds even for the social sustainability indicators. There is thus little indication that sustainability characteristics trigger negative sensory expectations. In fact, a survey study found that consumers expect sustainable diets to be tasty (Van Loo, Hoefkens, & Verbeke, 2017), and a taste intervention with more 'climate friendly' meals showed that these did not dissatisfy consumers (Visschers & Siegrist, 2015). In another study, however, consumers expressed a preference for natural yoghurt, but actually liked the taste of natural yoghurt less (Hemmerling, Canavari, & Spiller, 2016). This suggests nevertheless that there might be a gap between consumer expectations and experience.

3.1.3. Insect-based food

Reducing the consumption of meat and dairy products is one of the major and most frequently mentioned suggestions to improve sustainability of food consumption (Foley et al., 2011; Reisch et al., 2013). A considerable number of studies have looked at insect-based foods as an alternative nutritional source. They generally find that insect products are liked less than meat (Caparros Megido et al., 2016). Key barriers to favourable assessment or consumption, besides the sensory characteristics, include food neophobia (that is, dislike of unknown and new foods) and feelings of disgust (Hartmann & Siegrist, 2016) as well as the perceived inappropriateness of the category for eating (Tan, Fischer, van Trijp, & Stieger, 2016). These barriers seem to be much more difficult to overcome than actual sensory perception (Tan, Tibboel, & Stieger, 2017). Consumers with previous experience and familiarity with 'entomophagy', however, are more likely to hold positive attitudes towards insect food (Caparros Megido et al., 2014; Caparros Megido et al., 2016). Information can increase ratings of taste expectations

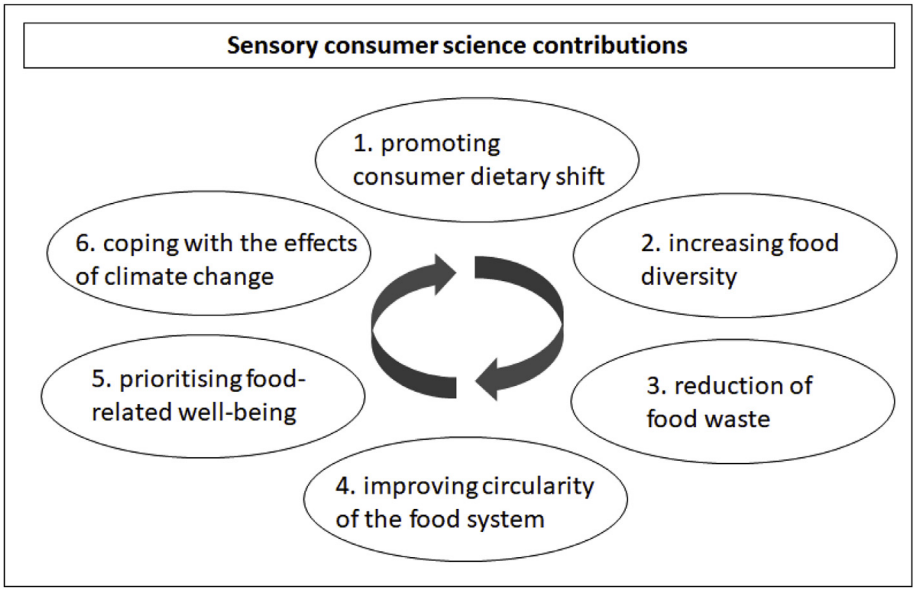
Sensory consumer science contributions
1. promoting consumer dietary shift
2. increasing food diversity
3. reduction of food waste
4. improving circularity of the food system
5. prioritising food-related well-being
6. coping with the effects of climate change

Fig. 2. Sensory consumer science contribution to six necessary transformations towards sustainable development in the agriculture and food sector.

(Caparros Megido et al., 2014), and this also holds for information impacting assessments when can actually tasting the food (Hartmann & Siegrist, 2016; Tan et al., 2016).

3.1.4. Meat replacements

In addition to insects, there are other potential replacements for meat or animal-based products. 'Cultured meat' has been studied and appears to trigger a similar reaction as insect food in terms of disgust (Verbeke, Marcu et al., 2015) and low sensory expectations. However, by providing relevant information, consumer willingness to try can be increased (Verbeke, Sans, & van Loo, 2015). Other meat substitutes (such as Tofu and quorn) might be less affected by disgust, but lack of familiarity, food neophobia, concerns about differing quality of amino acid profiles, and low sensory expectations are among the barriers identified or discussed (Hoek et al., 2011). Tasting, however, might increase liking over time, at least for some items and consumer groups (Hoek, Luning, Weijzen, et al., 2013).

3.2. Conclusions on current research streams

Overall, it appears that liking and acceptance of foods from organic agriculture can be improved by increasing the salience of products being organic. This is because many consumers have favourable expectations regarding organic food. Similarly, liking and acceptance of sustainable foods can be boosted by increasing consumer awareness of the sustainability impact. Liking and acceptance of insect foods and alternatives to meat can be increased by improving familiarity, providing information, and getting consumers to actually taste the product so that their low expectations can be disconfirmed.

The reviewed findings give the impression that in terms of sensory perception of more sustainable food options, there are two categories. The first category is favourably, and the second is unfavourably perceived food concepts. The first and more established group of organic and sustainable foods might simply have improved a lot in terms of taste throughout the decades of product development and refinement: organic had a negative sensory image 20–30 years ago, quite contrary to today's findings. The alternative explanation is that it has taken time to become 'mainstream'. A product that is more mainstream has gained a positive image that generates positive expectations and a halo effect on sensory perceptions. In line with theoretical models on consumer satisfaction, it is probably a combination of both (Anderson, 1973; Caporale & Monteleone, 2004) favourable expectation and a reasonable satisfaction of the latter.

Regarding the second group of insect foods and meat replacements, results indicate that information is needed to generate positive expectations and to induce trial and acceptance. However, it is important that the expectation is confirmed by the actual product experience. The process of new product uptake is complicated by the fact that insect food is hindered by disgust (Hartmann & Siegrist, 2017; Shelomi, 2015). Acceptance of many meat replacement products and the underlying technologies, though, is hampered by consumers' distrust in food technology (Lusk, Roosen, & Bieberstein, 2014) and the preference for 'naturalness' (Román, Sánchez-Siles, & Siegrist, 2017). However, the urgency of dietary transformation entails a need to speed up the adoption process of sustainable foods of any kind. This can be done by drawing, among other things, on sensory consumer science.

4. Sustainable transformation and the role of sensory consumer science

There are straightforward and obvious contributions that sensory consumer science can make to sustainable development, in particular where there already is research to build on. There are, however, also less straightforward connections between sensory consumer research and sustainability, which might gain a greater role in the long term. Most contributions belong to an optimistic scenario, that is, suggestions to help achieve sustainable development. However, some contributions are needed in case of a pessimistic scenario of humanity failing to achieve sustainable development. In the latter scenario, coping with drastic climate change, negative long-term effects of resource over-use, and social inequality is on the agenda. We present a categorization of the sustainable transformation needed and discuss the contributions of sensory consumer science to meeting the sustainable development challenges ahead (see Fig. 2). We start with the straightforward contributions and in an optimistic scenario, and finalize with the long-term contributions and in a pessimistic scenario.

4.1. Dietary shift towards lower impact foods

Sensory consumer science can contribute to the support of the dietary shift away from high impact beef and other meat and dairy products, and towards plant-based diets and alternative protein, such as insects or cultured meat. This shift reduces the environmental impact of diets and improves the efficiency of the food chain to ensure food

security for all. More concretely, the role of sensory consumer science is to explore ways to create positive expectations and willingness to try, and then satisfactorily meet or exceed expectations, to increase liking, acceptance and adoption. This can be achieved through reducing barriers to trying new products, create positive expectations towards new foods that can realistically be met, and improving sensory quality. The dietary shift is about specific foods as well as dietary patterns, as, for example, research on vegetable liking (Dinnella et al., 2016) or on diverse strategies to reduce the share of meat in the diet (De Boer et al., 2014; Dagevos & Voordouw, 2013; Schösler, de Boer, & Boersema, 2012).

There is an imbalance of the nitrogen and phosphorous cycles (Cordell, Drangert, & White, 2009). This calls for a dietary shift towards crops that need less fertilizer input and especially towards crops that fix nitrogen themselves, e.g. leguminous plants. Generally overlooked by consumers is also how their dietary choices impact agricultural practices and thus affect the conservation of soils or fresh water withdrawal. To name some examples, organic farming systems lead to soils with greater microbial activity (Lori, Symnaczik, Mäder, Deyn, & Gattinger, 2017), traditional farming techniques require less irrigation, and certain globally sought-after crops deplete water tables in already draught core production areas (such as almonds in California). In addition, there are crops whose production leads to especially problematic outcomes with regard to the mentioned planetary boundaries that are exceeded, such as palm oil plantations accused of leading to deforestation. Supporting a consumer preference shift can facilitate a change towards lower impact crops and more resource-efficient or preservative agricultural practices.

In the food versus fuel debate, the use of food crops such as sugar cane, oil seeds and maize for energy is criticized as decreasing food security (Mc Carthy et al., 2018). However, given the requirement of a substantial increase in the share of renewable energy (Holden et al., 2014), one could also argue that it is good if a dietary shift would free a share of food crops for bioenergy in order to increase the supply of renewable energy – at least until sufficient non-food bioenergy sources are ready for use. Currently, a major share of these crops are used to process foods of low nutritional value, thus foods contributing to obesity problems (Monteiro, Moubarac, Cannon, Ng, & Popkin, 2013). Given good health is an element of the human development index that should improve as well in order to achieve social sustainable development (Holden et al., 2014), a dietary shift should in general move consumption to healthier options.

Interestingly, a sustainable dietary shift might not necessarily only entail a shift towards 'natural foods' and non-technological systems that environmentally-minded consumers tend to prefer (Román et al., 2017). Sustainable alternatives to meat, however, might be highly processed, and at times the negatively perceived modern technologies and management systems can nevertheless contribute to sustainable food security (Mc Carthy et al., 2018). Thus, consumer research needs to work towards improving consumer trust and acceptance of such sustainable alternatives.

4.2. Greater food diversity

There should not only be a shift among, but also a broadening out of the crops, varieties and foods we eat. This would help fill the production gap and would allow making use of a greater assortment of potential foods. This supports and safeguards genetic biodiversity (Steffen et al., 2015) and a greater resilience of the system.

Such a diversification requires increasing the acceptance and liking of certain foods and decreasing scepticism and food neophobia. It also requires increasing acceptance of diversity in food appearance and taste a well as of a greater diversity of meal solutions. This includes seasonal differences in the foods offered so that, among other things, demand for airfreight food is lessened. A contradiction in the latter is that globalisation in principle allows a greater assortment of foods - for example by making exotic fruits accessible to consumers in the North - and triggers consumers' interest in new and foreign dietary options and flavours. However, at the same time, globalisation results in diets becoming more similar across the globe and year-round, which often leads to consumers turning away from and forgetting the potential of traditional, local and seasonal sources.

A greater diversity of crops and varieties also goes hand in hand with smaller and/or more locally adapted agricultural production units, which can support more resilient ecological and economic food systems (Döring et al., 2015; Foley et al., 2011). Such a more diverse and less concentrated food system can potentially come along with a more equal wealth distribution - as requested for sustainability (Holden et al., 2014). This would contribute to social equity goals of sustainable development.

4.3. Loss and waste reduction

Sensory consumer science can contribute to waste avoidance and thereby to a reduction in demand in a number of ways. Consumers' greater acceptance of a wider range of food options, as explained above, can keep down food waste of and avoid that we lose out on the potential for human nutrition that is entailed in under-used resources and currently wasted by-products. Research on quality improvement and prolongation of shelf life may create additional food waste avoidance: good quality foods are less likely to be wasted by consumers, and foods with a longer shelf life more likely reach the stage of actual human consumption instead of being wasted due to passing the expiry date (Spada, Conte, & Del Nobile, 2018). In addition, consumer research might help alleviate the expectation of an overly perfect appearance, and instead improve acceptance of 'sub-optimal' foods (De Hooge et al., 2017). Consumer sensory science can also contribute to tackling unnecessary anxiety and wrong food safety perceptions that lead to unnecessary food waste. Here again, it is a challenge that environmentally-minded consumers are less likely to accept technologies such as those helping to increase shelf life (Cavaliere & Ventura, 2018).

4.4. More circular food systems

In the long run, the food system needs to become more circular. A cradle-to-cradle approach (Braungart, McDonough, & Bollinger, 2007) requires the exclusion of toxic substances – whether from pesticide use, food processing, or consumers ingesting heavy metals, like mercury, medicine which by-passes waste-water treatment, or hazardous nanoparticles. This entails changes in food choices and diets. It requires consumers to accept and not to be disgusted by the waste-to-value idea, and it need consumers to collaborate in what it might take, for example by capturing the phosphorous from human waste to be used as fertilizer (Cordell et al., 2009). Furthermore, this can consist of conducting correct household waste separation, engaging in composting or grow-your-own, accepting foods from urban and vertical farming, or meat from animals fed with insects (Shelomi, 2015) or waste. Sensory consumer science can explore ways to support consumer acceptance of new food and food-related behaviours needed in a circular food system.

4.5. Priority to food-related well-being

In order to decrease the impact, not only food consumption patterns have to change but the overall scale of per capita consumption needs to decrease. Only then resources will be more distributed fairly, and thus social equity goals of sustainable development achieved. Growth in human prosperity and well-being should therefore use other indicators than gross domestic product (GDP). Sensory and consumer food science can contribute by providing measures of sensory experience and sensory-derived 'satisfaction and wellbeing', and contribute to exploring and improving food satisfaction and happiness. This can, for example, be from the tasty and enjoyable food that consumer-citizens eat, the

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way they eat in company, and the 'flourishment' they might experience from self-determined food production, handling and creation of meals. This way human needs can be shifted towards products and services with low impact or even a positive environmental contribution, instead of being derived from a materialistic consumption culture and the purchase of objects. This would allow to decouple growth in prosperity from resource use (Jackson, 2017).

4.6. Coping with climate change beyond the 2 Celsius threshold

While most efforts discussed in the literature aim at a successful sustainable transformation of societies, the challenge is of such a magnitude that this goal might not be achieved 'in time'. Climate experts warn that beyond the 2 Celsius threshold of global warming, the changes in our environment and thus our food production base will be drastic. In that case, there are a number of ways sensory consumer science can help cope with the less fortunate scenario.

After climate change, the regionally most adequate crops will shift. It might be more draught resistant crops and varieties, plants which can make better use of a high CO_2 concentration, crops that grow under higher temperatures, or that can withstand heavy rain and winds. Again, this creates a need for dietary shift and consumer acceptance of new foods. However, under these conditions, consumers may have less freedom of choice than today and may be forced to accept any food available, whether tasty or not. Nevertheless, securing satisfaction with foods is important to e.g. lessen the likelihood of social unrest in times of crisis. Some foods may have accumulated too many toxics to be eaten or should only be eaten with restrictions, requiring consumers to shift their dietary habits away from these items or follow specific instructions. Overall, less agricultural land will be available due to rising sea levels and desertification, thus requiring even more dietary shifts, diversifying of food sources, and waste avoidance (Alcamo & Olesen, 2012).

If social equity is not prioritized in sustainable development, societies might become more divided. There might be an elite which can afford all sorts of foods and sensory experiences, and the masses living in food insecurity and shortage. In consequence of more disastrous climate change impact, sensory consumer science might need to work towards developing foods for disaster relief action and foods adequate to be stored for the case of power outages. Ultimately, the discussion on climate change impact often brings up the thought - although an unrealistic option - of whether humanity can move into space or relocate to other planets. This scenario would require adequate foods developed for space missions and space station food systems.

5. Conclusions

The sensory consumer science discipline can 'make sense' for sustainability. We compare the predictions and requirements for a sustainable transformation of the food sector with the currently existing research streams in the discipline. Based on that, we propose that sensory consumer science can and should contribute to six necessary transformations: 1) promotion of consumer dietary shift to more sustainable foods and diets, 2) increase in food diversity, 3) reduction of food waste, 4) improvement of the circularity of the nutrient and food system, 5) heightening and prioritising food-related well-being, and 6) coping with the effects of climate change. So far, research in the discipline and under the explicit topic of 'sustainability' has majorly engaged in the first and partly in the second. Future research should be directed to the other points as well, and sensory consumer science should take more explicit departure in the requirements for a sustainable transformation. The discipline's research work can more effectively contribute to a sustainable development of the food sector when it aims for a contribution to one or more of the six necessary transformations. As such, the sensory consumer science discipline will help tackle humanity's challenges ahead.

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